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The effect of using tubular flanges in bridge girders with corrugated steel webs on their shear behaviour – A numerical study

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ABSTRACT

Due to the reduction in the financial plans in recent years, innovative bridge girders with corrugated webs have been widely studied and used to reduce the construction costs. Additionally, flat flanges have in some cases been replaced by hollow tubular flanges. These two innovative solutions have been found separately to provide girders with superior load carrying capacities. This paper, however, tries to combine the advantages of the corrugated webs and the hollow tubular flanges into one structural bridge girder. Accordingly, bridge girders with corrugated webs and hollow tubular flanges (BGCWTFs), which have seldom been considered in literature, are investigated here under constant shear loading. This is done by using Abaqus software on large-scale girders, with the main aim of examining the influence of using hollow tubular flanges on the strength and behaviour of these BGCWTFs. Opposite to what was previously found in literature, the results show the great effect of adding upper and lower tubular flanges to the strength and stiffness of the girders compared with the case of flat flange girders, though using tubular flanges with small depth-to-width ratios is found insignificant. The fundamental behaviour of the BGCWTFs has been addressed and the shear strengths are compared with available design model for the first author. Overall, the current results show the importance of considering the shear contribution from the flange with large depth-to-width ratios.

1. Introduction

1.1. Corrugated web girders

Although steel girders have been used for a long time, a new generation of corrugated web girders is developed by the advances in structural and fabrication technologies by the end of the 1980s. Almost three decades after its discovery, girders utilising corrugated webs have been widely used in bridges and long span beams around the world [1–3]. Typically, these girders are built-up flexural members, with each girder consisting of a corrugated web that is welded to two flat flange plates. Generally, trapezoidal and sinusoidal corrugations, shown in Fig. 1, are used in bridges and buildings, respectively. Opposite to I-plate girders with conventional flat webs, corrugated webs do not contribute in transferring the longitudinal stresses from flexure. Hence, in case of laterally restrained girders with corrugated webs, the moment capacity is merely controlled by the flange yielding or local buckling depending on its class (i.e. fully effective or slender flange). This is a direct result of their profiling or what is so called the accordion effect [4,5]. Therefore, the general behaviour of the corrugated web girder is close to the lattice girder [6–11], wherein the bending moments and normal forces are carried only by the flanges, whereas the transverse forces are only carried by the diagonals and verticals of the lattice girder (in this case the corrugated web). Indeed, the corrugated web increases the girder's stability against web shear buckling, resulting in a very economical design by the elimination of web stiffeners, which are essential for flat webs. The significant out-of-plane stiffness of the corrugated webs reduces the web thickness as well relative to conventional flat webs [1–5]. In a recent study, Zevallos et al. [12] suggested to use two corrugated web plates with small thicknesses (similar to that suggested by Kim et al. [13]) instead of a single web plate of a large thickness to increase the strength-to-weight ratio of the girder. Accordingly, this may facilitate and accelerate the production of these girders by benefiting from the recent improvements in the automatic welding in the fabrication process of the corrugated webs which became possible up to 6 mm thickness [12].

1.2. Hollow tubular flange girders (HTFPGs)

The advances in structural and fabrication technologies have also

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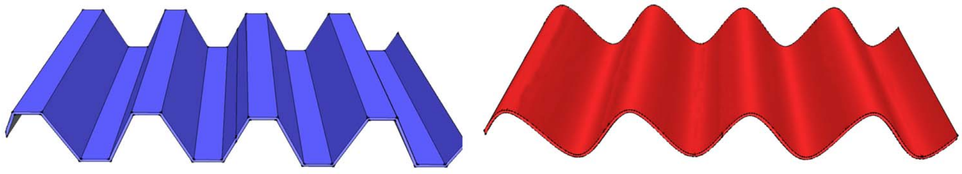
(a) Trapezoidal corrugations (b) Sinusoidal corrugations

Fig. 1. The cross-sectional forms of the corrugated sheets almost used in structural applications.

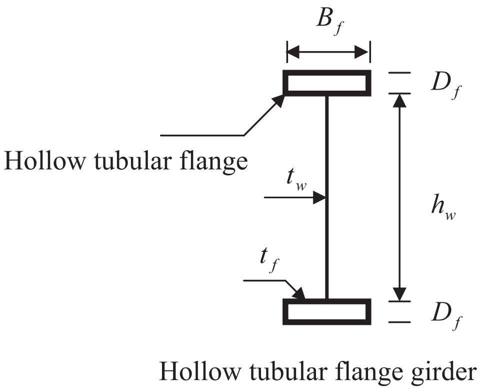

Fig 2. A typical plate girder with hollow tubular flanges.

Fig. 3. Inclined bridge girders with corrugated steel webs.

led to the development of the hollow tubular flange girders [14–16], with the main aim of increasing the lateral-torsional buckling of these girders. However, a design engineer should ensure that the designed element is safe under different possible failure modes, from which the shear failure being one of them. This encouraged the current authors to investigate the effect of adding these tubular flanges to I-girders by suggesting using the hollow tubular flange plate girders (HTFPGs) rather than the conventional I-plate girders (IPGs) [17,18], as can be seen in Fig. 2. It was found that the shear strength of the new plate girders (i.e. HTFPGs) increases owing to the additional flange anchorage to the tension field compared with IPGs, besides the additional vertical flange elements (with depth D_f) that share in resisting the applied vertical shear force. To the authors view point, using the HTFPGs may be useful in carrying the transverse shear on the inclined girders (see Fig. 3), at which such shear may be carried better by both flange plates of the width B_f. To the authors' best knowledge; there exist at least two practical engineering instances of bridge girders with tubular flange girders filled with concrete and corrugated webs. The first is the Maupre Bridge which consists of a box girder of triangular section, a concrete-filled tubular bottom flange and a prestressed concrete deck [19]. The other one is the 30 m span prestressed composite bridge with bottom tubular flange girders filled with concrete [20], as shown in Fig. 4. This new type of composite structure consists of superimposed concrete slab with steel plate, corrugated steel webs and rounded-ended rectangular tubular bottom flange filled with concrete. The excellent mechanical properties have been verified by a full-scale experiment, as shown in Fig. 4. This has been recently confirmed by the experimental results undertaken by Shao and Wang [21,22].

1.3. Problem statement and scope of the paper

Coincidently, the idea of combining the corrugated webs with the compressive and tensile rectangular tubular flanges has been suggested by Wang [23]. The objective of that research [23] was to explore the fundamental behaviour of different tubular flange members with corrugated webs that are subjected separately to shear, bending and axial compression. The work [23] included both full-scale testing and nonlinear finite element (FE) analyses. However, they considered two experimental small-scale specimens to explore the shear behaviour of these girders, with web depth (for the deeper beam) and thickness of 400 and 2.1 mm, respectively. The flange width, depth and thickness were 200, 50, 6.3 mm, respectively. Based on the test and FE results [23], it was concluded that tubular flanges do not seem to have considerable influence on the ultimate shear strength. To the authors' belief, this final conclusion needs additional confirmation due to some logical reasons. The first is related to the fabrication of one of the specimens, at which the web was poorly corrugated, as observed by Wang [23], from which the fold line between the inclined and horizontal folds in the corner region was not vertical. Furthermore, the material properties of the tubular flanges were not measured, and the shear calculations were based on the manufacturer material properties. Hence, to the authors' experience, using the actual material properties was going to lead to accurate analyses than those made by Wang [23]. Accordingly, this paper firstly shed the light that additional experimental tests of such girders should be conducted to provide more accurate results to literature, especially by using the corrugation sizes used in actual bridges and large tubular flanges (which are available in the US but not yet existing in Egypt). Additionally, the existing laboratory facilities in the home institution of the first two authors do not support the investigation of full scale bridge girders, which are the focus of this paper. Moreover, the conclusion of Wang [23] that the shear is merely carried by the web was based on testing small-scale beams with hollow flange size and web thickness that are below what would be used in bridges and long span beams. Additionally, the fact that the tubular flange has insignificant influence on the shear buckling resistance of plate girders needs additional verification based on the results of Jáger et al. [24]. According to Jáger et al. [24], the effect of the tubular flange depends on the ratio of the cross-sectional areas of the flange to the web of the girder (A_f/A_w). Based on above discussion, this paper investigates numerically the shear behaviour and strength of large-scale steel bridge girders composed of corrugated webs and tubular flanges (BGCWTFs), despite the fact that the flanges of these girders in reality would be filled with concrete [15]. Based on the recommendation of the AISC [25] to calculate the shear strength of concrete-filled steel tubular members by considering either the shear strength of the steel tubular section alone or that of the concrete core